The Measurement of the Attenuation of Light by Water in SNO A Robust Method Using a Horizontal Optical Path

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Abstract

An improved robust method for measuring the attenuation of light by water using a horizontal optical path has been developed for the SNO experiment. Results are presented for measurements of the optical clarity of samples from different stages of the water purification process.

1 Introduction

The SNO experiment uses a large heavy water and light water Cherenkov detector. The Cherenkov light is primarily in the blue and UV, so that the attenuation of light at these frequencies will determine the energy calibration of the detector; it is thus important to monitor the light attenuation by the actual water in the detector.

Boivin et al., at NRC, measured the attenuation of light in ultra-pure light and heavy water, and showed that the heavy water is a suitable liquid for the SNO detector. Their measurements were done using a 50 cm long quartz cell and a mercury vapour arc lamp. The measurements required great care to control the systematic effects and their method is thus not well suited for routine monitoring in the mine.

A new technique, using a laser as a light source and a variable height water column, was developed and shown to be sufficiently sensitive for the routine measurements underground. The method however was very sensitive to vibrations, since the light had to cross a horizontal water surface.

A new method, using a horizontal optical path was developed. This method has several advantages:

- The light crosses no horizontal water surfaces and is thus less sensitive to vibrations.
- The method can be used 'inline' by using the water trough as a bypass.
- The measurements can be readily and quickly repeated.

The disadvantages are that it uses a corner cube mirror that is moved on a precision track that needs careful alignment, and there are many components in or near the water, which thus need to be selected carefully.

2 Apparatus

The present design consists of a He-Cd laser, a 2.5 meter trough of water, with a flat quartz entrance window at one end, a corner cube mirror suspended from an adjustable precision track, and an optically sensitive diode in an integrating sphere. Figure 1 is a schematic of the apparatus.

The intensity of the He-Cd laser can be monitored using a partially reflecting mirror and a second diode; however, the laser beam was found to be sufficiently stable to make this unnecessary.

The laser beam is adjusted to be parallel to the precision track. The corner cube mirror will reflect the laser back along a path that is parallel and displaced from the incident beam. The integrating sphere is placed to intercept the reflected light.

The attenuation can be measured by observing the change in intensity as the mirror is moved along the track, changing the optical path length through the water. Care must be taken that the mirror moves parallel to the incident laser beam light and does not rotate, so that the reflected beam always enters the integrating sphere at the same spot. The precision track can be adjusted to remove local non-uniformities.

The light intensity is measured by the optical diode in the integrating sphere, which produces a voltage proportional to the light intensity. The voltage is measured with a three and a half digit DVM.

3 Method

The laser is aligned by placing a grid target over the mirror and ensuring that the laser beam hits the mirror at the same spot for the full length of the track. Fine adjustments to the track are then made by placing a grid target in front of the integrating sphere and ensuring that the reflected beam does not wander as the mirror is moved along the track.

Once the system is aligned, a 'dry' run is performed. This information is used to measure the accuracy of the alignment, and the data is used to 'correct' the measurement on the water.

The trough is filled with the water to be sampled and three runs are taken, each with 20 measurements spread over an optical path change of 3 meters.

The measurement at the shortest distance is assumed to be the initial intensity. The relative intensity at any distance is taken as the average of the three ratios of intensity over initial intensity. An error of 0.5% is assigned to these relative intensities; this is the reading error on the measurements, and seems to also be approximately the reproducibility of the results. This is probably a reasonable estimate, since the χ^2 for the fits appear to be in the right range.

For the 'corrected' intensity, the relative intensities for the measurements on water are divided by the relative intensity for the 'dry' run at the same position. The data from the 'dry' run is also analysed as though it represented an attenuation, called the equivalent attenuation length, giving some indication of the precision with which we can expect a measurement to be made.

The data is handled using PAW. The data is fit to an exponential using the standard PAW fitting routines, and then plotted.

4 Results

The track can be adjusted so that the 'dry' run gives an equivalent attenuation length of about 700 meters, certainly good enough for SNO. However, it is found that the alignment changes with time, and the track needs to be realigned before an accurate measurement can be made on very clear water. The track was typically adjusted to a precision such that the measurements on the water were not significantly affected by any residual misalignment.

The attenuation length was measured for tap water, water after the 3 micron filter, water after the reverse osmosis stage, and water after the ionpure stage. The water in the recirculation cycle was also measured. The figures showing some of the results are included; the figures for the uncorrected data are shown for all sets, and for the water from the ionpure stage the figures for the corrected data and the 'dry' run are also included. The results for all data are shown in the following table.

Water Sample	Uncorrected attenuation length	Corrected attenuation length	Dry Run equivalent attenuation length
Tap water	1.80±0.01 m	1.86 m	50.7 m
3 micron filter	4.36±0.03 m	4.77 m	48.8 m
Reverse Osmosis	31.9±1.3 m	34.2 m	455. m
Ionpure	$150.^{+32.}_{-23.}$ m	192. m	697. m
Recirculation	$70.4^{+6.6}_{-5.8}$ m	78.2 m	719. m

5 Discussion

The track was adjusted to a precision appropriate to the clarity of the water. With care, the apparatus can be adjusted to reliably measure attenuation lengths of a few hundred meters, more than adequate for SNO. It should be pointed out that all these measurements were made with blue light (425 nm), which, because of its smaller attenuation, is a better measure of the precision that can be attained with the apparatus.

The uncorrected attenuation lengths can be taken as a lower limit of the actual attenuation length, since there is always some residual misalignment in the system. However, it is not clear that correcting for the measured misalignment in the 'dry' run gives the correct answer, since the addition of water changes the optics of the whole system, especially at the quartz window. The corrected attenuation lengths should thus be considered as a guide to the systematic error due to misalignment.

The water clarity improves as the water progresses through the purification plant, and finally reaches a clarity of better than 100 meter attenuation length right after the ionpure stage. The theoretical limit (Rayleigh scattering only) for the attenuation length at this wavelength is approximately 200 meters. The water in the recirculation loop loses some of its clarity, presumably due to leaching and residual contaminants in the recirculation loop.

The system is designed to allow the use of an Argon atmosphere above the water, which was used to prevent the water from absorbing oxygen, and which should reduce problems with rusting. The problem of rusting should disappear when all components are replaced with stainless steel components. The life of the mirror is a concern and a coating similar to the PMT reflector coating may have to be applied. It is disturbing that the track needs to be aligned on a regular basis, and some further development may be required to resolve this problem.

The tests should be repeated with UV light, where the attenuation is expected to be larger, and thus more important, but also easier to measure accurately.

6 Conclusion

A quick robust method, suitable for underground operation, has been developed for SNO and used to measure the optical clarity of the water at various stages in the purification plant. The technique is satisfactory and only minor improvements are foreseen at this time.

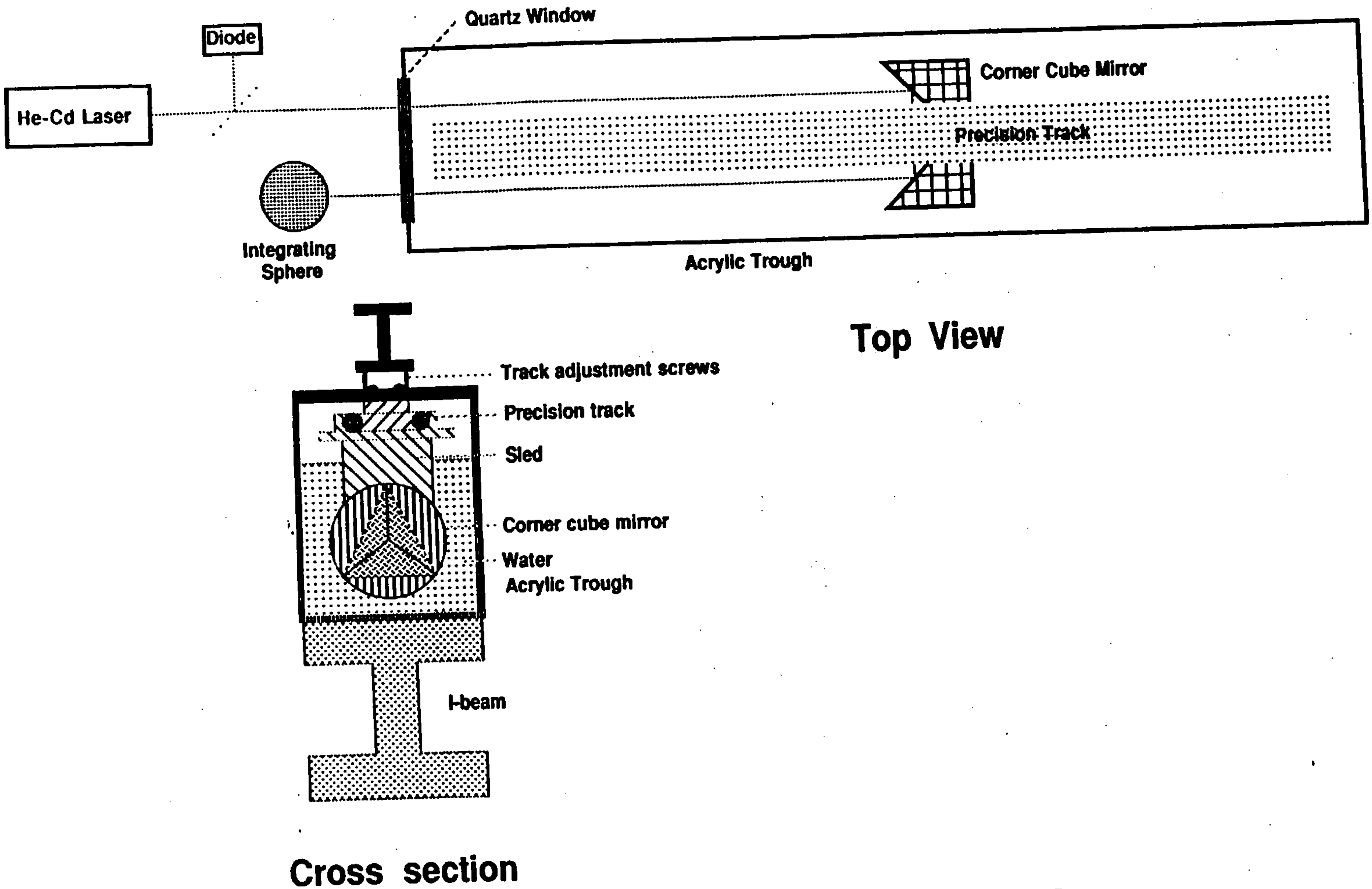
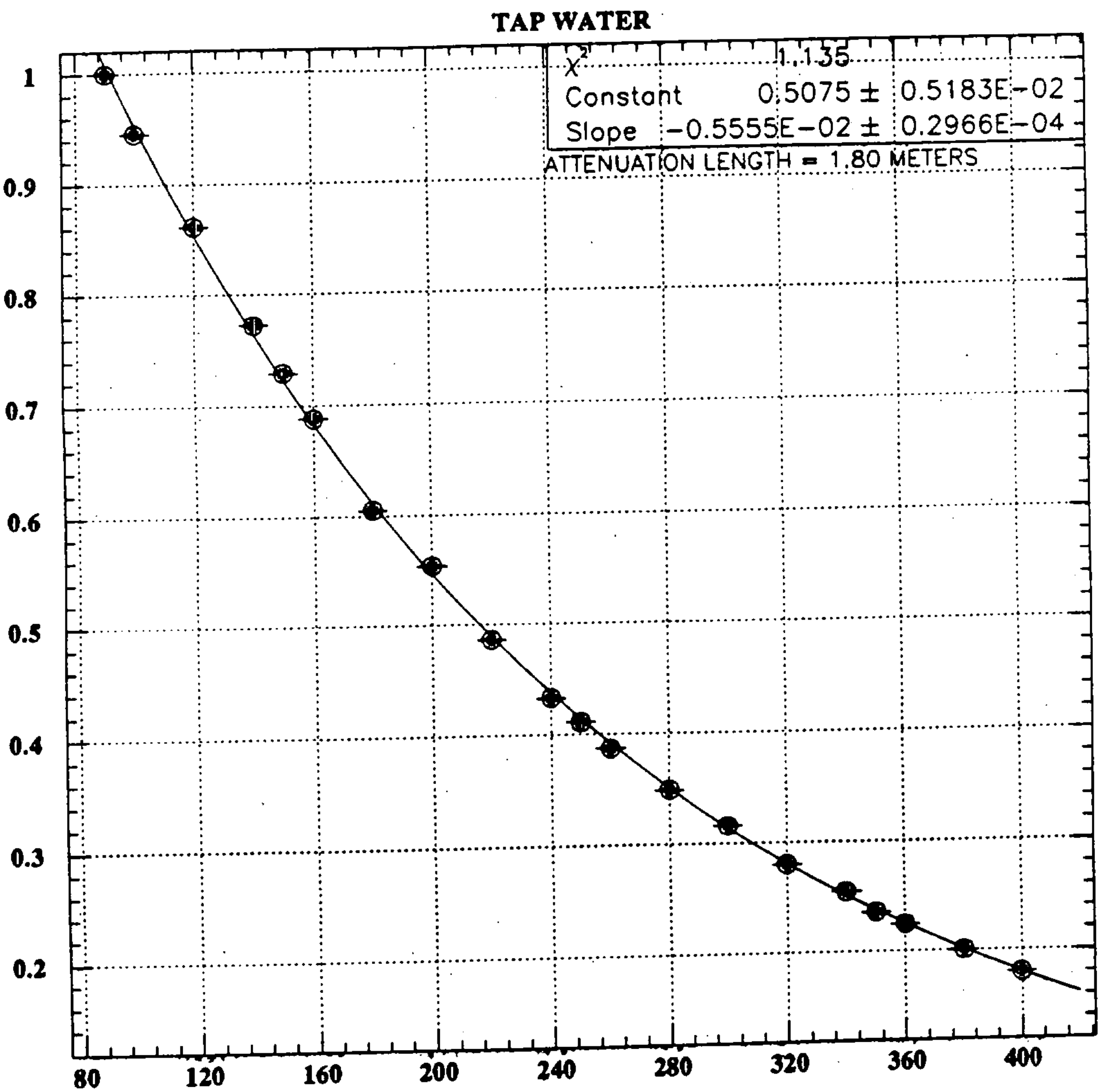
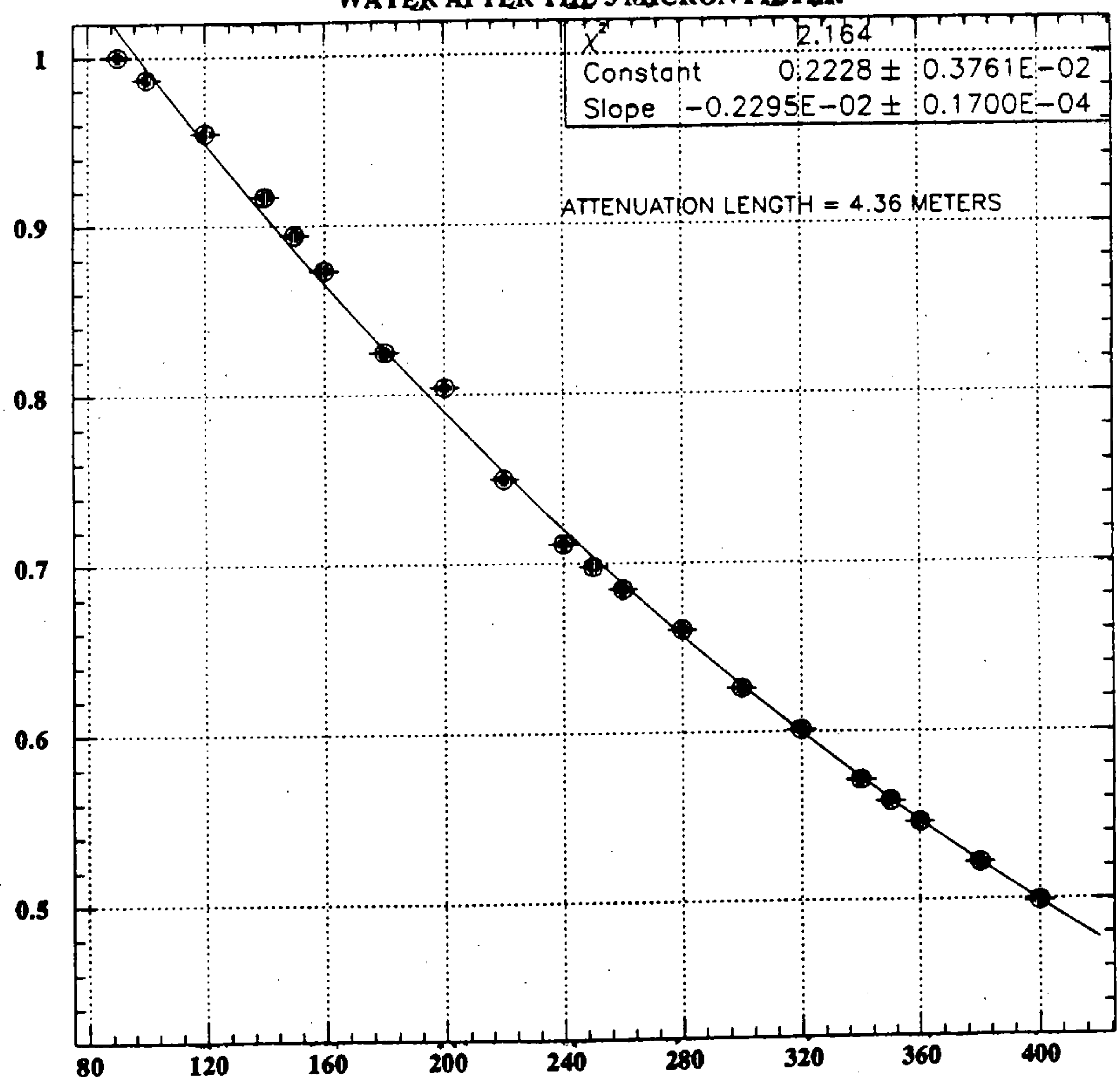


Figure 1 - Schematic of Apparatus

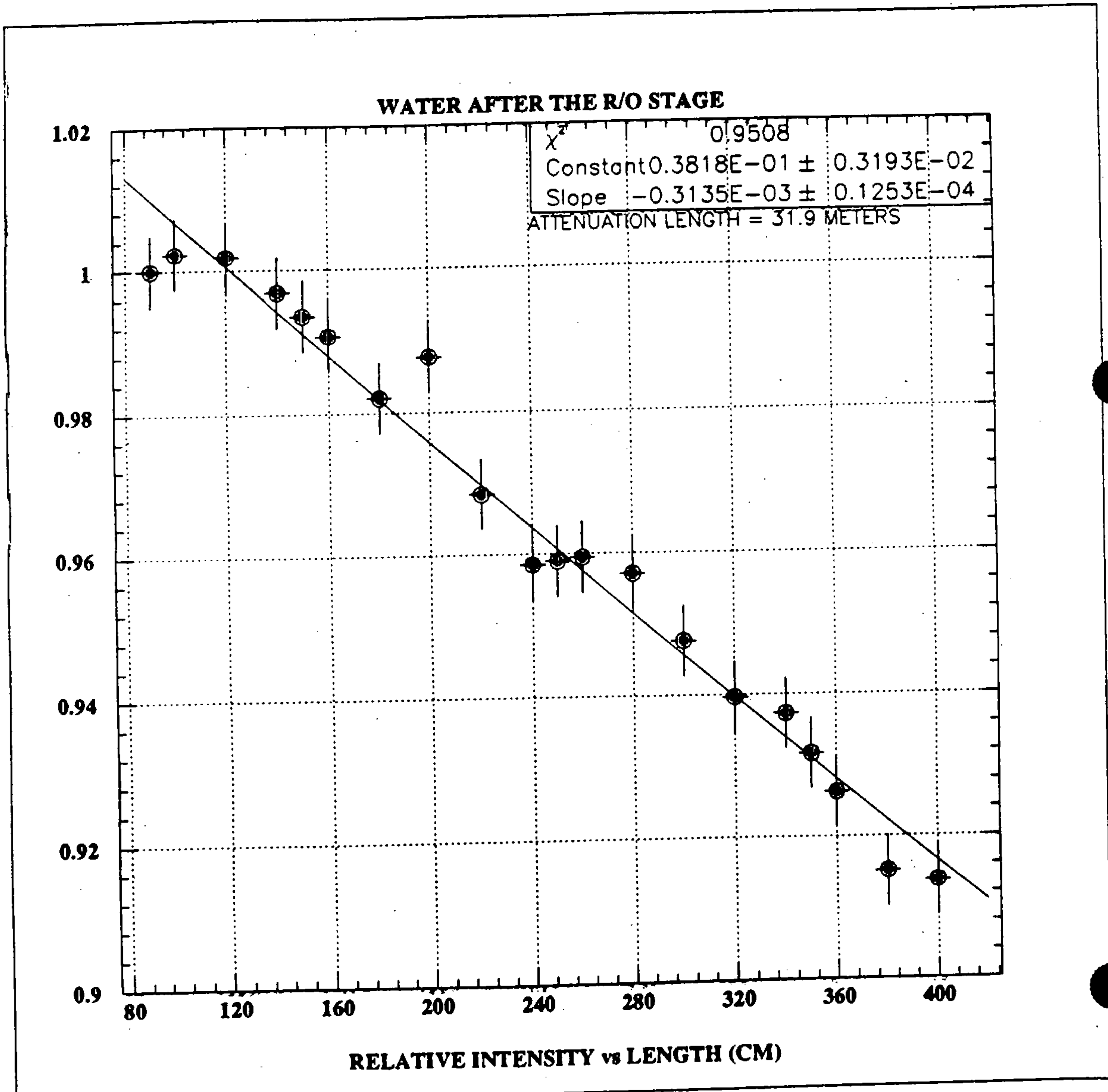


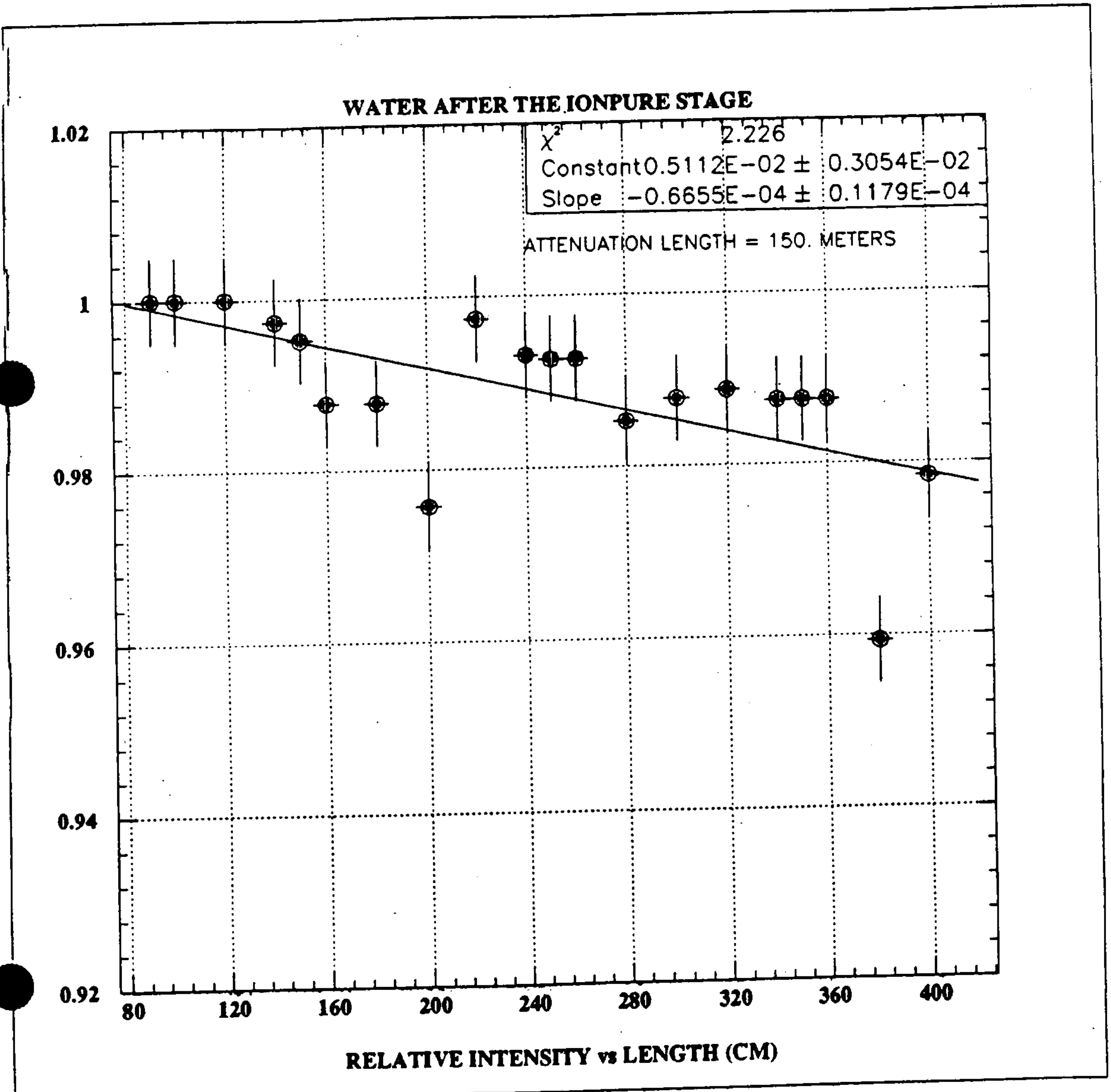
RELATIVE INTENSITY vs LENGTH (CM)

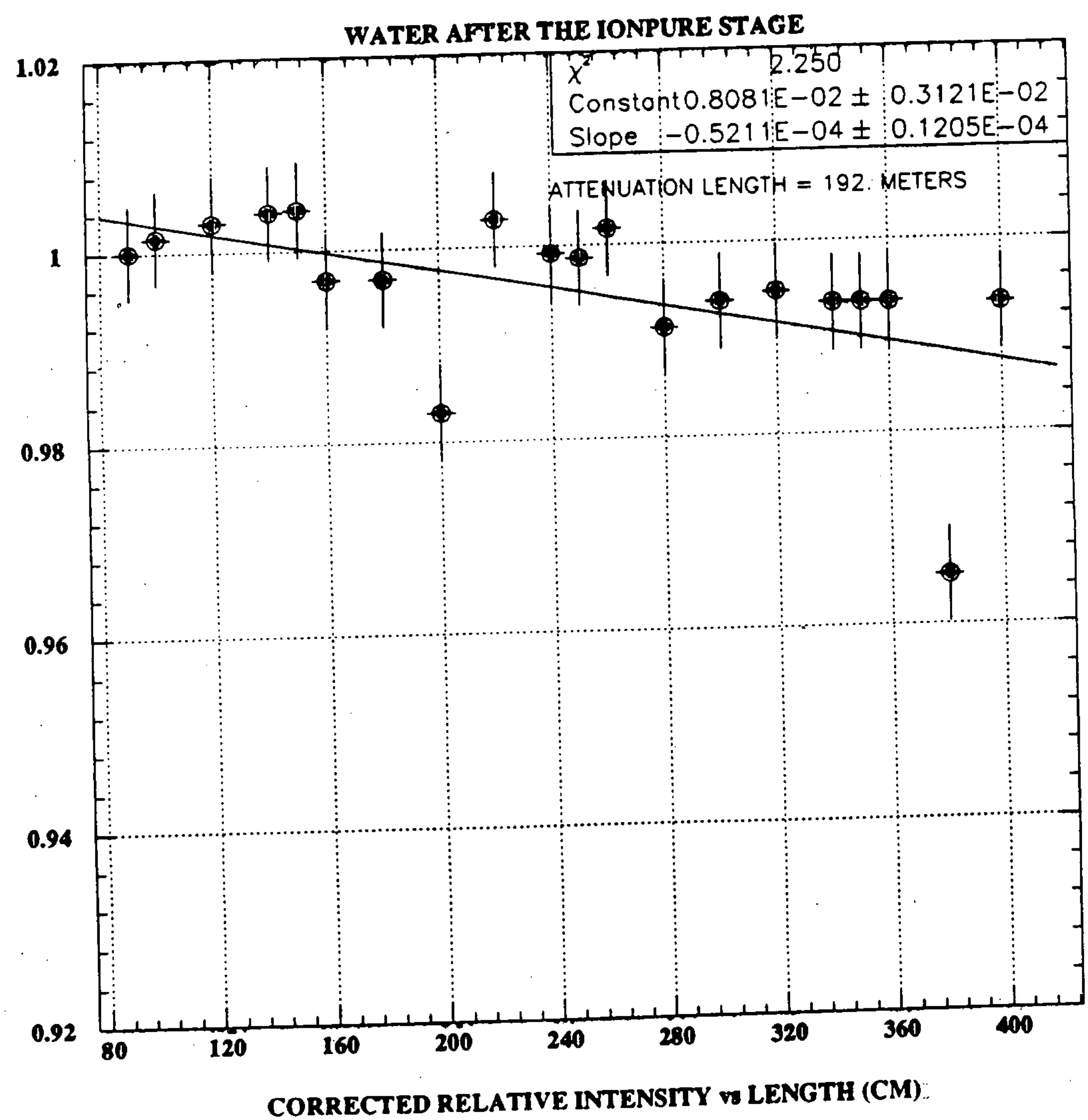
WATER AFTER THE 3 MICRON FILTER

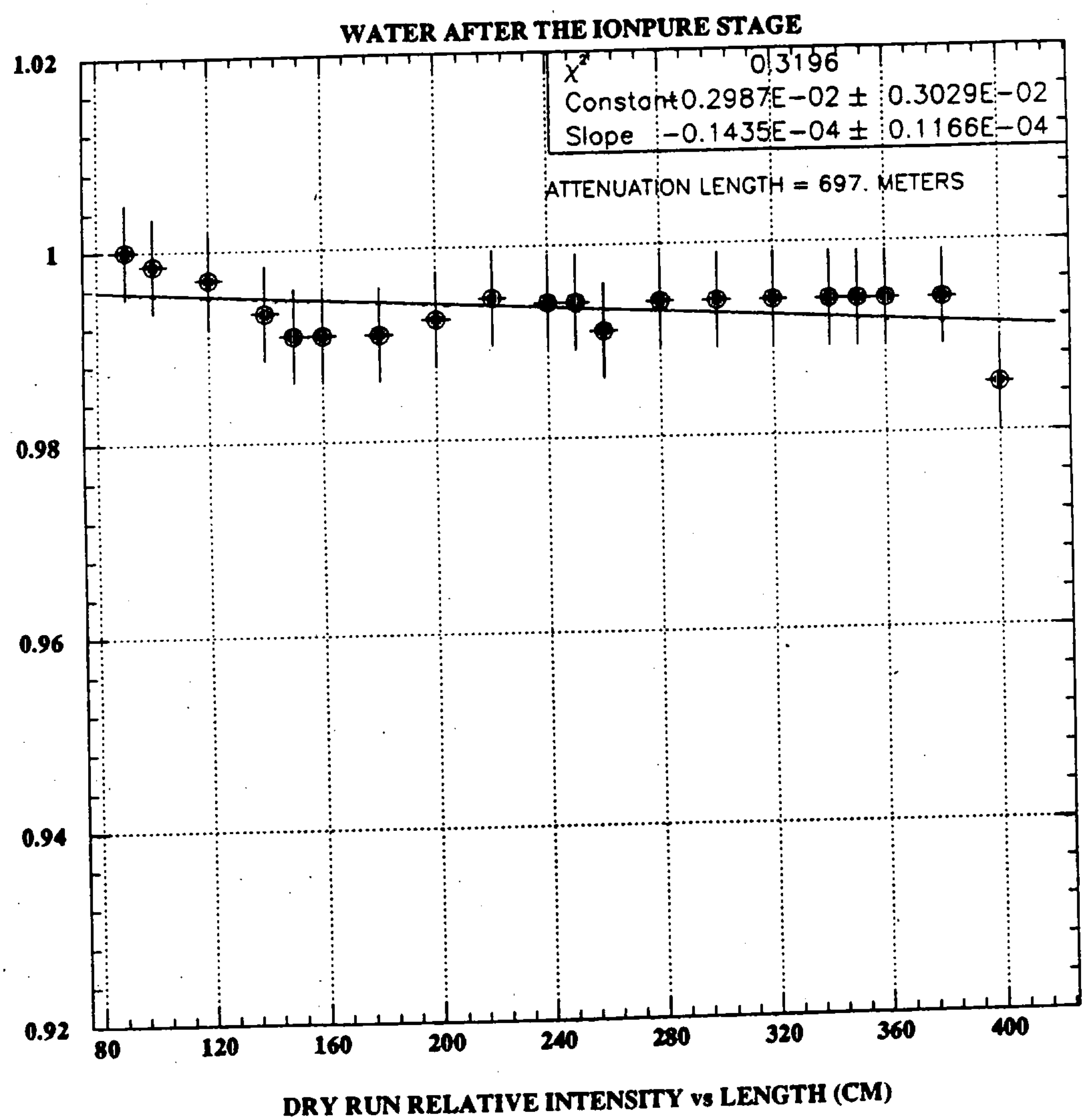


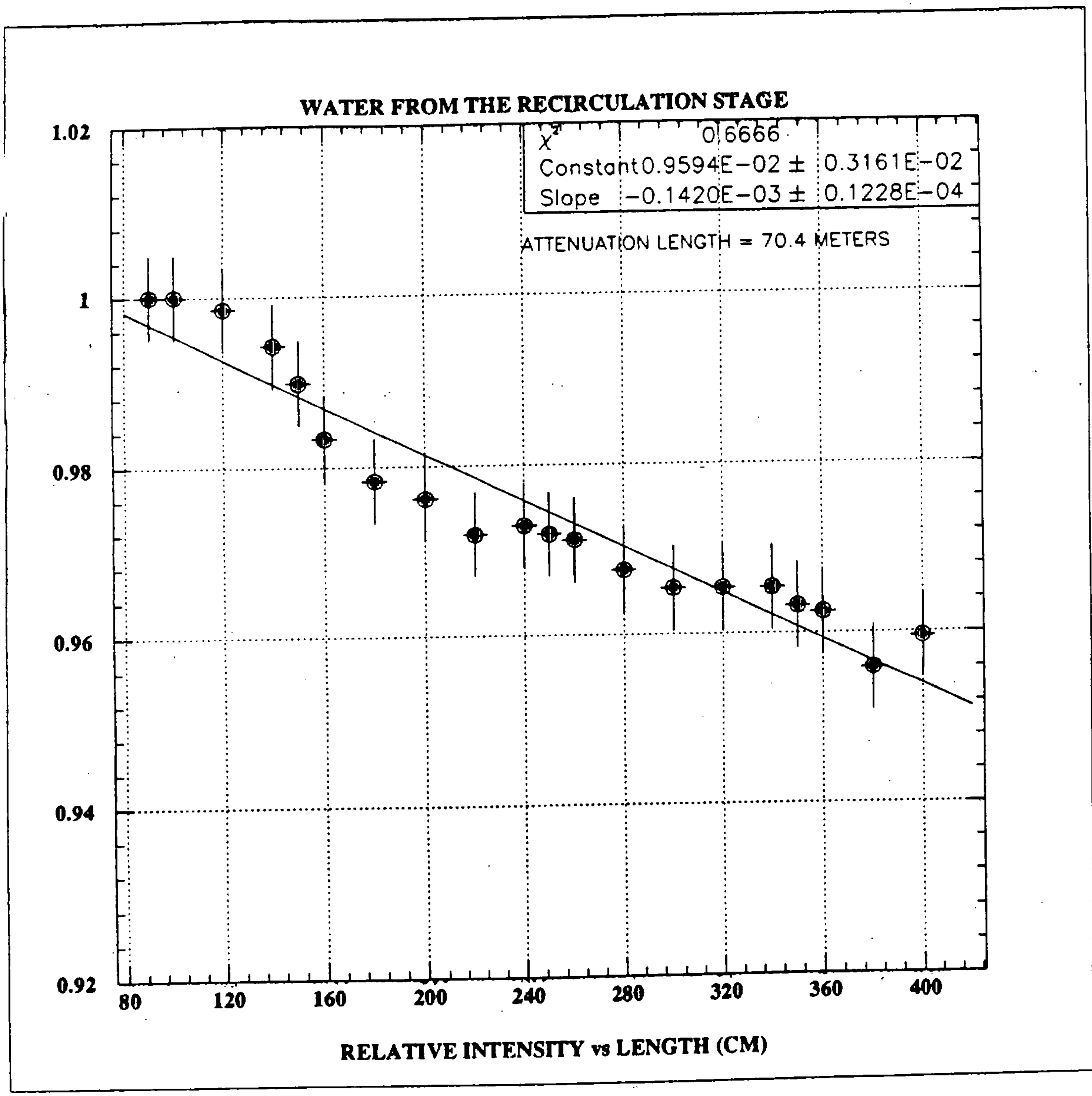
RELATIVE INTENSITY vs LENGTH (CM)


WATER AFTER THE R/O STAGE
χ^2 0.9508
Constant 0.3818E-01 ± 0.3193E-02
Slope -0.3135E-03 ± 0.1253E-04
ATTENUATION LENGTH = 31.9 METERS
1.02
1
0.98
0.96
0.94
0.92
0.9
80
120
160
200
240
280
320
360
400
RELATIVE INTENSITY vs LENGTH (CM)


WATER AFTER THE IONPURE STAGE
χ² 2.226
Constant 0.5112E−02 ± 0.3054E−02
Slope −0.6655E−04 ± 0.1179E−04
ATTENUATION LENGTH = 150. METERS
1.02
1
0.98
0.96
0.94
0.92
80
120
160
200
240
280
320
360
400
RELATIVE INTENSITY vs LENGTH (CM)


WATER AFTER THE IONPURE STAGE
χ^2 2.250
Constant 0.8081E−02 ± 0.3121E−02
Slope −0.5211E−04 ± 0.1205E−04
ATTENUATION LENGTH = 192. METERS
1.02
1
0.98
0.96
0.94
0.92
80
120
160
200
240
280
320
360
400
CORRECTED RELATIVE INTENSITY vs LENGTH (CM)


WATER AFTER THE IONPURE STAGE
χ² 0.3196
Constant 0.2987E−02 ± 0.3029E−02
Slope −0.1435E−04 ± 0.1166E−04
ATTENUATION LENGTH = 697. METERS
1.02
1
0.98
0.96
0.94
0.92
80
120
160
200
240
280
320
360
400
DRY RUN RELATIVE INTENSITY vs LENGTH (CM)


WATER FROM THE RECIRCULATION STAGE
χ² 0.6666
Constant 0.9594E−02 ± 0.3161E−02
Slope −0.1420E−03 ± 0.1228E−04
ATTENUATION LENGTH = 70.4 METERS
1.02
1
0.98
0.96
0.94
0.92
80
120
160
200
240
280
320
360
400
RELATIVE INTENSITY vs LENGTH (CM)